Aiash, Mahdi ORCID logoORCID: https://orcid.org/0000-0002-3984-6244, Mapp, Glenford E. ORCID logoORCID: https://orcid.org/0000-0002-0539-5852, Lasebae, Aboubaker ORCID logoORCID: https://orcid.org/0000-0003-2312-9694, Loo, Jonathan, Sardis, Fragkiskos, Phan, Raphael, Augusto, Mario, Moreira, Edson and Vanni, Renata M. P. (2012) A survey of potential architectures for communication in heterogeneous networks. In: Wireless telecommunications symposium (WTS), 2012. IEEE, pp. 1-6. ISBN 9781457705809. [Book Section] (doi:10.1109/WTS.2012.6266121)

A Survey of Potential Architectures for Communication in Heterogeneous Networks

Mahdi Aiash, Glenford Mapp, Aboubaker Lasebae, Jonathan Loo, Fragkiskos Sardis*, Raphael Phan†
Mario Augusto, Edson Moreira‡, Renata Vanni§
*School of Engineering and Information Science
Middlesex University, London, UK
Email: M.Aiash, G.Mapp, A.Lasebae, J.Loo, F.Sardis@mdx.ac.uk
†Electronic and Electrical Engineering
Loughborough University, Loughborough, UK
Email: R.Phan@lboro.ac.uk
‡ ICMC, University of Sao Paulo, San Carlos, Brazil
Email:marioeaugusto@gmail.com, edson@icmc.usp.br
§ Federal Institute of Education, Science and Technology, Campus Araraquara, Brazil

***Abstract*—An increasingly wireless world will mean that devices with multiple network interfaces will soon become commonplace. Users will expect to be always connected from anywhere and at any time as connections will be switched to available networks using handover techniques. However, different networks have different Qualities-of-Service so a Quality-of-Service Framework is needed to help applications and services deal with this new environment. In addition, since these networks must work together, future mobile systems will have an open, instead of the currently closed, architecture. Therefore new mechanisms will be needed to protect users, servers and network infrastructure. This means that future mobile networks will have to integrate communications, mobility, quality-of service and security. This paper provides an overview of potential architectures for communication in future networks. Our study shows that only a number of these architectures support this integration.**

I. Introduction

The world is experiencing the development and large-scale deployment of several wireless technologies; these range from next generation cellular networks to personal/home networks such as WLANs and metropolitan ones such as WiMax. Users will expect to be connected to several networks at the same time and ubiquitous communication will be achieved by seamless switching between available networks using handover techniques [1]. Since handover in this scenario will happen more frequently and in order to support macro and micro mobility management, there is a need to integrate mobility with the communication framework more closely.

Furthermore, since different technologies have different characteristics in terms of speed, latency and reliability, vertical handover will therefore have an impact on the network service experienced by ongoing applications and services as mobile nodes move around. Some applications such as multimedia may be able to adapt, while others may need support to deal with varying Quality-of- Service (QoS). This situation is also reflected on the server side which must be ready to adapt its service delivery when the QoS or security parameters change. So Service Level Agreements (SLAs) must be adapted to handle changing network conditions.

As pointed out in [2], vertical handover can cause radical changes in QoS. Hence, it is important that as much control as possible is exercised by mobile devices to achieve optimum vertical handover. It is therefore necessary to develop new techniques which could make other layers of the protocol stack aware of impending handover decisions and thus allow them to take steps to minimize the effects. So a new QoS Framework is required which must be integrated with mobility mechanisms such as handover.

Due to the fact that, the connectivity in the peripheral networks will be based on a wide variety of wireless technologies, provided by different operators, various network operators need to cooperate and coexist in the core network. Furthermore, new providers might choose to join the network and share the spectrum. Unlike current communication systems such as 2G and 3G, which introduce closed environments where the core network is controlled and owned by single network operators and thus its security is mainly based on the assumption that the core network is physically secure, the above discussion highlights the fact that we are moving towards an open, heterogeneous environment where the core network is not controlled by a single operator, so multiple operators will have to cooperate.

Taking into account the observation above, and in addition to the fact that connectivity in heterogeneous networking will be based on IP addresses as described in [3], this situation will give rise to a number of security threats such as Denial-of-Service (DoS) attacks that we see in the Internet today. So security must also be integrated into future mobile networks to deal with these threats. However, current communication architectures, such as the IP Protocol Suite, were not initially designed to operate in heterogeneous environments and hence, they cannot provide the required mechanisms to meet the aforementioned requirements of future networks. This highlights the need for new communication architectures that

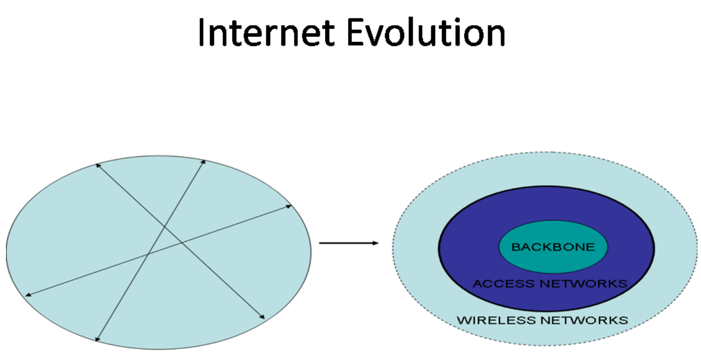

Fig. 1. The Future Internet Structure

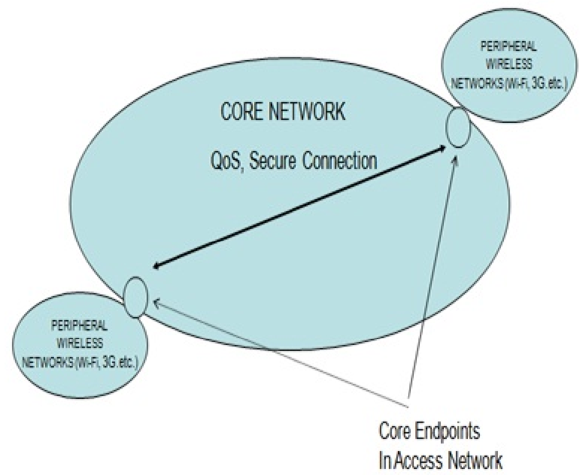

Fig. 2. The Concept of Core-End Points

consider the open nature of future networks and address issues of QoS, security, mobility in an integrated manner.

This paper presents a comprehensive survey of possible communication architectures for heterogeneous networks i.e., the Mobile Ethernet as described in [5], [6], Ambient Networks explained in [17], IEEE 802.21 [7], [8] and the Y-Comm framework [11]. The main contributions of this paper are:

- to evaluate the historical evolution of network and communication architecture for heterogeneous systems, and
- to pinpoint the advantages and possible weaknesses of these architectures including those of IEEE 802.21, Ambient Networks, the Mobile Ethernet and the Y-Comm Framework.

The rest of this paper organized as follows: Section 2 overviews the trend of evolving the current Internet to support heterogeneous networks. Section 3 describes potential communication architectures for future networks, namely the IEEE 802.21, the Ambient Network, the Mobile Ethernet and the Y-Comm framework. These architectures are compared and analysed in Section 4. The paper is concluded in Section 5.

II. Network Evolution to Support Heterogeneous Networks

The widespread use of wireless technologies has highlighted a significant evolution in Internet Architecture. In terms of performance, it is now possible to divide the Internet into two distinct parts: a core network and edge or peripheral networks. As shown in Fig 1, the core network consists of a super-fast backbone and fast access networks which are attached to the core. The backbone network is being made fast by the use of optical switches while the access networks are being upgraded using MPLS techniques. On the other hand, the peripheral network will be dominated by the deployment of wireless technology. This means that the characteristics of the core network will be very different from the characteristics of the peripheral wireless network on the edge. This change needs to be reflected in new networking architectures to clearly define the functions, the order and the interlocking relationships that are necessary to support different functionalities such as handover, security and QoS in heterogeneous environments. By considering the above-described changes of the network structure, different research efforts such as the Daidalos II architecture [4], the Mobile Ethernet framework [5] and the International Telecommunication Union (ITU-T) [12] have been working on defining a new architecture for heterogeneous networks. These working groups have agreed on the need for a central management entity to control and manage the resources of the different networks in the local area. This concept of a central management entity has also been adopted by the Y-Comm group via introducing the concept of the Core-End Points (CEPs) in [13], [14], [15], [16] as central administrative domains that control the operation of different network operators as shown in Fig 2.

III. Future Communication Architectures for Heterogeneous Networks

This section describes potential frameworks for future networks and highlights their strong and weak features.

A. The IEEE 802.21 Standard

The IEEE 802.21 Working Group has developed standards to enable handover and interoperability between heterogeneous network types including both 802 and non-802 networks. As stated in [8], the purpose of IEEE 802.21 is to improve user experience by providing Media Independent Handover (MIH) functionality that facilitates both mobile-initiated and network-initiated handovers.

To optimise handover in heterogeneous environments, the IEEE 802.21 has proposed an intelligent and generic interface that operates between the data link (L2) and network layers (L3) of the protocol stack. This interface holds all the required functions to support MIHF and thus is referred to as Media Independent Handover Functions (MIHFs), these functions should be available in the Mobile Terminal (MT) and the network entities. More details about the functions and their responsibilities are found in [8].

Analysis: The IEEE 802.21 standard provides functions and libraries to support vertical handover in heterogeneous networks. Also, its proposed vertical handover system could be considered as a reference model for future communication frameworks.

Although the IEEE 802.21 claimed to adopt an open architecture, it did not specify how the different network operators could join the network and collaborate with other operators. Also, the IEEE 802.21 model initially came with no security features in mind and only recently, some security-related features were introduced, i.e. security solutions introduced by the Handover Keying Working Group (HOKEY WG) [10], [3]. Recently, some other enhancements were proposed to add a QoS negotiation stage to the handover model as in [9]. Furthermore, the IEEE 802.21 does not introduce a communication architecture to support the integration between QoS, security and mobility within a well-defined communication framework.

B. Ambient Networks

Ambient Networks [17] is an architecture designed to support heterogeneous networking. It is specially focused on providing seamless connectivity using a common control interface around different networks, thus converting them into Ambient Networks which are characterised by three interfaces: the Ambient Service Interface, the Ambient Network Interface and the Ambient Resource Interface. There are 4 layers in the Ambient Network design. The Connectivity Layer describes the links and infrastructure used to connect two Ambient Networks together. The Flow Abstraction layer is used to define the connectivity provided by different networking technologies and to control and manage the connectivity layer. A flow is an abstract view of the connectivity provided by the underlying network technology. Flows are also defined by flow endpoints and may also pass through intermediaries called flow transits. The Bearer abstraction is a higher level abstraction which is not as location specific as flows. Bearer endpoints therefore use a unique naming space which allows mobility, address translation and media manipulation to be supported. Finally, the Application layer allows applications on Ambient Networks to use the architecture. The system therefore supports a much more flexible approach to internetworking in general which means that a global networking address can be replaced by high-level entity-names.

Analysis: Ambient Networks is based on IP connectivity. However, it extends the concept of an All-IP Network by the following three main innovations:

- **Network Composition:** Unlike the current Internet, internetworking in Ambient Networks is represented at the higher level of the architecture as well as at the basic addressing and routing levels. As stated in [17], Ambient Networks function across operator and technology boundaries, it has to be transparent and executable with minimum users involvement.

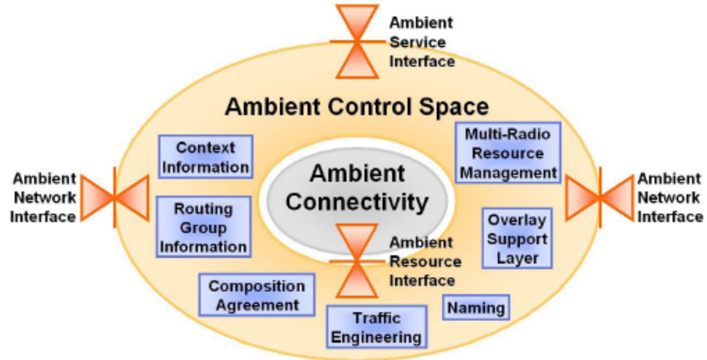

Fig. 3. The Ambient Networks Structure [17]

- **Mobility:** As stated in [17], Ambient Networks focus on integrated mobility concepts that deal with inter and intra-domain mobility. Furthermore, mobility must interact efficiently with the control interfaces needed to enable quality of service and optimal routing and re-routing of individual multimedia flows.
- **Heterogeneity:** Ambient Networks will support multiple technologies of different operators. This will provide ubiquitous communication and enable the user to use the best available network. As shown in Fig 3, the resource and network interfaces of the Ambient network would help in accommodating new networks and managing their resources, thus supporting an open environment.

Furthermore, Ambient networks consider security as a key factor that must be provided from the very beginning of the design. Fig 3 shows the Ambient Network Architecture.

C. The Mobile Ethernet Architecture

Mobile Ethernet Architecture is a Beyond 3G network system for the all IP integrated network using MAC layer technologies [5], [6]. The architecture is based on the Wide Area Ethernet (WAE) which is a virtual private network aimed at providing connectivity based on the Ethernet (MAC) addressing and thus achieves interoperability among different IP-based operators.

As shown in Fig 4, in order to achieve scalability and interoperability among different operators, the Mobile Ethernet proposes a network partitioning scheme. In this scheme the network will comprise a fast ring core network which aggregates a number of segments, each segment is attached to a one or more of peripheral networks via a number of edge switches.

Analysis: Furthermore, two types of handover are introduced in Mobile Ethernet:

- *Intra-Segment handover*: Mobility is managed in a distributed manner because each switch in the segment tracks the location of the terminal as long as it is still within the same segment. More details about Inter-Segment Mobility Management including the procedures for location regeneration and update could be found in [6].

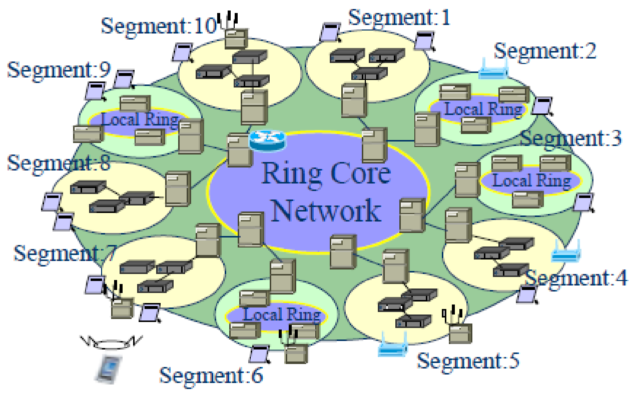

Fig. 4. The Mobile Ethernet Network Structure [6]

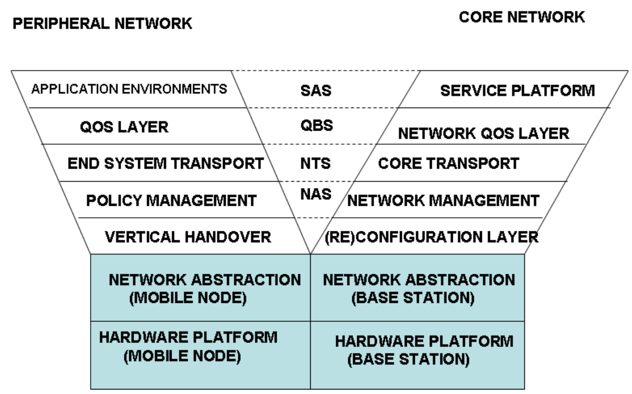

Fig. 5. The Y-Comm Complete Structure

- *Inter-Segment handover*: An Inter-Segment Mobility management provides the required functionalities to manage the handover among different segments in the core network, this includes setting up the path between segments and sending location update information to track the terminal's movement. Further details are found in [6].

Additionally, in [5], [6], a secure service framework for Mobile Ethernet was proposed. The framework comprises the following elements: the mobile terminal (MT), a Contact-less smart card to hold user credentials, and a self-delegation unit between the smart card and the terminal. As explained in [5], [6], the framework aims to provide security at different levels, namely: network, service and personal levels. To achieve this, a self-delegation protocol was introduced. This protocol achieves authentication between the mobile terminal and the smart card and then delegates the terminal to perform authentication with the service provider and the network operator.

However, the Mobile Ethernet framework does not introduce a model for supporting mobility. Also, QoS is not directly considered in the architecture. Furthermore, Mobile Ethernet presumes a physically secure core network and thus does not really adopt a fully open environment.

D. The Y-Comm Framework

The Y-Comm FrameworkY-Comm [11], [20], [19] is a communication architecture to support vertical handover for multi-homed nodes in heterogeneous environment. The architecture has two frameworks:

- **The Peripheral framework** deals with operations on the mobile terminal.
- **The Core framework** deals with functions in the core network to support different peripheral networks.

As shown in Fig 5, the two frameworks share a common base subsystem consisting of the hardware platform and network abstraction layers. Both frameworks diverge in terms of functionality but the corresponding layers interact to provide support for heterogeneous environments. To support multi-homed nodes, the Network Abstraction Layer (NAL) contains the drivers of different networks and thus provides a common interface that supports different networking technologies. Additionally, issues such as network operability and overlapping are addressed by this layer.

Analysis: As described in [19], Y-Comm supports reactive and proactive models of the vertical handover. With reactive handover, the mobile terminal (MT) makes the decision to handover as a response to layer 2 events such as fading signal strength or the presence of a neighbouring network with a better QoS. In proactive handover, the MT, while still in the current network, attempts to determine when and where handover should occur.

In order to provide an end-to-end QoS in heterogeneous networks, the Y-Comm group has proposed in [13] a novel network structure and operational entities. The future Internet will comprise a super-fast core network which is attached to much slower, mainly wireless peripheral networks via Core-End Points (CEPs). As shown in Fig 6, each Core-End Point manages different technology-specific domains that are in turn connected to one or more peripheral access networks. The CEPs will be responsible for managing the resources of the different networks and enable the collaboration between them, thus supporting a fully open environment.

To address the QoS issue in heterogeneous systems, new components have been proposed such as the Centralized QoS Broker (CQoSB) in the CEP and the Domain QoS Brokers (DQoSBs) in each domain. Authentication, Authorizing, Auditing and Cost (A3C) servers are used for security reasons in the CEP and low level domains as well.

As shown in Fig 5, Y-Comm deploys a multi-layer security module which must be applied to both the Peripheral and Core Framework simultaneously to provide total security. The security layers must work together across both frameworks in order to be fully integrated with the new architecture. The security module comprises four layers:

- **Service And Application Security (SAS):** authenticates the user to use the mobile terminal.
- **QoS Based Security:** looks at QoS issues, e.g., Service Level of Agreements (SLA), network overloading and Denial of Service Attacks (DoS) in both the core and peripheral networks.

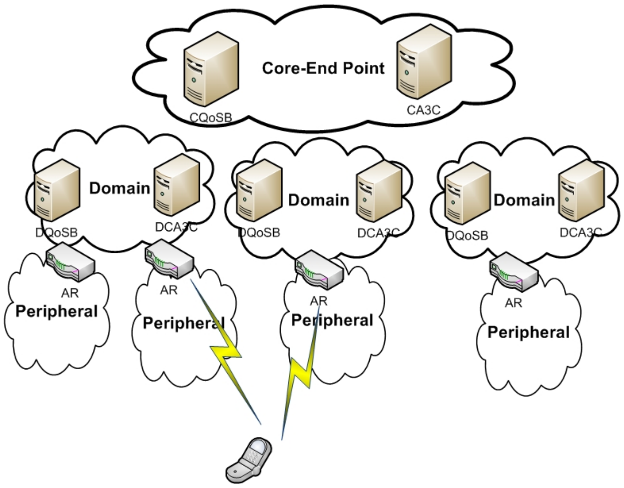

Fig. 6. The Network Structure as Proposed by the Y-Comm

- **Network Transport Security (NTS):** sets a secure session between the mobile terminal and the end server.
- **Network Architecture Security (NAS):** it defines the security issues and threats resulting from moving to a particular network type.

IV. Comparing the Different Architectures

This section compares and contrasts the architectures described in section III.

- **Considering an End-to-End QoS Provision:** Unlike the Mobile Ethernet, the IEEE 802.21, Ambient Networks and Y-Comm consider End-to-End QoS provision by defining QoS frameworks as explained in [9], [18] and [13] respectively.
- **Integrated Security Approach:** The Y-Comm and Mobile Ethernet introduce a security framework which is fully integrated with the communication procedure. However, as stated in [3], the IEEE 802.21 has started to consider implementing the Pre-Authentication security protocols of the HOKEY WG solutions [10]. Ambient Networks system does not specify a novel security module, instead it considers current security mechanisms and utilizes them to guarantee that all communication and negotiation take place in a secure manner as stated in [18].
- **Defining Mobility Models:** Apart from the Mobile Ethernet, all the discussed architectures propose models for vertical handover in heterogeneous networks. Y-Comm and IEEE 802.21 proposed models to support different types of mobility such as reactive and proactive vertical handover as described in [19], [7].
- **Defined Communication Framework:** While Mobile Ethernet, Ambient network and IEEE 802.21 propose mechanisms to address issues like QoS, security and mobility, they do not present a communication framework to integrate these mechanisms. As explained in section III-D, Y-Comm defines a well-structured communication framework that provides full integration between QoS, security and mobility with the communication procedure.
- **Openness of the Network:** Unlike Mobile Ethernet, a fully open environment has been adopted by IEEE 802.21, Ambient Networks and Y-Comm architectures. However,Y-Comm, on the other hand, already supports a fully open environment, since the openness and dynamics of heterogeneous network were key factors when designing the mechanisms for security, QoS and mobility.

A summary of this comparison is shown in Table I:

V. Conclusion

To enhance user experience in heterogeneous environments, future communication architectures have to consider integrating communication, QoS, security and mobility. In this regard, this paper analyses four potential communication architectures namely, the IEEE 802.21, the Ambient Networks, the Mobile Networks and the Y-Comm framework. The analysis shows that this integration is partially considered by Mobile Ethernet and IEEE 802.21, more integration is supported by Ambient Networks, while Y-Comm supports full integration and introduces a well structured communication framework.

References

[1] S. Jochen: *Mobile Communications*. Addison Wesley, 2003

[2] J. McNair and F. Zhu. *Vertical Handoffs in Fourth-Generation Multi-Network*. IEEE Wireless Communications, 11, 2004.

[3] Y. Park and T. Park.*A Survey of Security Threats on 4G Networks* in. Commun. Networking Lab., Samsung Adv. Inst. of Technol. Globecom Workshops, IEEE. Washington, DC, pp. 1-6. 22-01-2008.

[4] M. Almeida, D. Corujo, S. Sargento, V. Jesus, and R. Aguiar. *An End-to-End QoS Framework for 4G Mobile Heterogeneous Environments*. OpenNet Workshop (2007).

[5] K. Masahiro, Y. Mariko, O. Ryoji, K. Shinsaku, T. Tanaka.*Secure Service and Network Framework for Mobile Ethernet*. Wirel. Pers. Commun. 29 (2004).

[6] K. Masahiro. *APG-Report: Scalable Mobile Ethernet and Fast Vertical Handover*. IEEE Wireless Communications and Networking Conference (2004)

[7] IEEE 802.21/D8.0. Draft Standard for Local and Metropolitan Area Networks: Media Independent Handover Services. 2007.

[8] K. Taniuchi, Y. Ohba, V. Fajardo, S. Das, M. Tauil, Y. Cheng, A. Dutta, D. Baker, M. Yajnik, D. Famolari. *IEEE 802.21: Media Independent Handover: Features, Applicability, and Realization*. IEEE STANDARDS IN COMMUNICATIONS AND NETWORKING. 2009.

[9] S. Fang Yang, J. ShyrWu. *A IEEE 802.21 Handover design with QOS provision across WLAN and WMAN*. International Conference on Communications, Circuits and Systems, 2008. ICCCAS 2008.

[10] Internet Engineering Task Force, Handover keying working group (hokey wg). http://www.ietf.org/html.charters/hokey-charter.html.

[11] Y-Comm Research. http://www.mdx.ac.uk/research/areas/software/ycomm research.aspx.. [Accessed 29 Jan 2012].

[12] International Telecommunication Union (ITU-T), Global Information Infrastructure, Internet Protocol Aspects And Next Generation Networks, Y.140.1, 2004.

[13] M. Aiash, G. Mapp,A. Lasebae. *A QoS framework for Heterogeneous Networking*. ICWN2011 (2011).

[14] M. Aiash, G. Mapp, A. Lasebae, R. Phan, J. Loo. *A Formally Verified AKA Protocol for Vertical Handover in Heterogeneous Environments Using Casper/FDR*. Accepted For publication in EURASIP Journal on Wireless Communications and Networking, 2012.

[15] M. Aiash, G. Mapp, A. Lasebae, R. Phan, J. Loo. *A Formally Veried Initial AKA Protocol in Heterogeneous Environments Using Casper/FDR*. Submitted For Publication in the International Journal of Information Security, Springer

TABLE I
A SUMMARY OF RESULTS

	QoS Framework	Integrated Security module	Mobility Models	A Structured communication Framework	Openness of the Networ
IEEE 802.21	Yes	Security is not built-in	Yes	No	Claims to support open enviro
Ambient Networks	Yes	Yes	Yes	No	Supported
Mobile Ethernet	No	Yes	No	No	Not supported
Y-Comm	Yes	Yes	Yes	Yes	Fully supported

[16] M. Aiash, G. Mapp, A. Lasebae. *Security and QoS Integration for Protecting Service Providers in Heterogeneous Environments*. International Journal of Computer Science, 2011.

[17] U. Horn,C. Prehofer, H. Karl. *Ambient Networks - An Architecture for Communication Networks Beyond 3G*. IEEEWireless Communications. vol. 11, no. 2 (2004).

[18] N. Niebert, A. Schieder, J. Zander, R. Hancock. *Ambient networks: co-operative mobile networking for the wireless world*. Wiley, 2007.

[19] G. Mapp, F. Shaikh, and M. Aiash, R. Vanni, M. Augusto and E. Moreira. *Exploring Efficient Imperative Handover Mechanisms for Heterogeneous Wireless Networks*. International Symposium on Emerging Ubiquitous and Pervasive Systems (EUPS-09), 2009.

[20] G. Mapp, F. Shaikh, D. Cottingham, J. Crowcroft, J. Beliosian. *Y-Comm: A Global Architecture for Heterogeneous Networking*.3rd Annual International Wireless Internet Conference (WICON 2007), 2007.